Report for 2004WA91B: Benthic Organisms and Flow Field Interactions: Improving Linkages and Descriptions

- Water Resources Research Institute Reports:
  - Stone, Mark C., Rollin Hotchkiss, and Richard Zack, Natural Stream Flow Fields: Measurements and Implications for Benthic Organisms, State of Washington Water Research Center, Washington State University, Pullman, Washington, Water Research Center Report No. WRR-22, 133 pp.
- Conference Proceedings:
  - Stone, Mark C., Rollin H. Hotchkiss, and R.R. Morrison, 2005, The influence of successional development on periphyton scour resistance, in proceedings of the World Water and Environmental Resources Congress, Anchorage, Alaska, 10pp.
- Dissertations:
  - Stone, Mark C., 2005, Natural stream flow fields: observations and implications for benthic organisms, Department of Civil and Environmental Engineering, College of Engineering and Architecture, Washington State University, Pullman, Washington, 200pp.

Report Follows

PROBLEM AND RESEARCH OBJECTIVES

Hydropower development, channelization of streams, water withdrawals, land use changes, and other anthropogenic activities have caused severe damage to aquatic ecosystems. To restore ecosystem processes and functions, we must advance our knowledge of these systems. This requires a better understanding of physical flow features and the influence of these features on aquatic organisms. Improved flow field descriptions will advance stream restoration efforts by allowing reproduction of important flow features. Advanced measurement techniques will allow for easier analysis of aquatic ecosystems. Increased knowledge of the influence of flow on aquatic organisms will improve our ability to manage and restore streams and rivers.

This research addressed this need by meeting the following objectives:

Objective 1: a) Evaluate the adequacy of existing empirical relationships for describing natural stream flow fields and b) investigate spatial distributions of flow variables

Objective 2: Test the adequacy of acoustic Doppler current profiler (ADCP) instruments for measuring velocity, shear stress, and turbulence distributions in cobble bed streams

Objective 3: Investigate temporal variations in periphyton resistance to shear stress

Objective 4: Investigate the influence of flow on benthic organisms by developing habitat suitability criteria (HSC) for periphyton assemblages and macroinvertebrates

METHODOLOGY

Objective 1 was met by characterizing mean and turbulent flow field distributions in two cobble bed river stream reaches. An acoustic Doppler velocimeter (ADV) was used to collected high frequency velocity data in three to four cross sections in each river. Observations were made at seven points per vertical profile at three to five stations in each cross section, for a total of approximately 100 samples per stream reach. Each reach was approximately 50 meters long and 15 meters wide and included riffle, run, and pool stream units. Data were analyzed to calculate mean and turbulence variables including turbulence intensity (TI), turbulent kinetic energy (TKE), correlations, and integral scales. The data were compared to laboratory derived empirical equations and the spatial heterogeneity was investigated in the horizontal and vertical planes.

Objective 2 was accomplished by conducting ADCP and ADV measurements at nine coincident stations in two cobble bed rivers. The ADCP was mounted in a Riverboat and anchored with taglines to the river banks. Data was collected for 20 minutes and the instrument position was marked and surveyed. The ADV was then placed in the same position and data were collected in a vertical profile. Velocity and shear stress measurements were statistically compared between instruments. A physical evaluation of ADCP turbulence measurements was also completed.

Objective 3 was completed by colonizing ceramic tiles in a stream for various time periods and then exposing the slides to increasing shear stress in the laboratory. The tiles were colonized for periods from 2 weeks to 12 weeks. Additionally, new tiles were colonized every two weeks to evaluate the effects of successional development. Following the shear stress exercise, the remaining periphyton was removed from the slides and the ash free dry mass (AFDM) was determined in order to calculate mass scour and percent scour. An ANOVA was completed to test a series of hypotheses.

Objective 4 was met by collecting periphyton AFDM and macroinvertebrate frequency samples in two stream reaches. The biological observations were combined with physical measurements of flow velocity, substrate size, and water depth. The data were then combined to investigate relationships between biological and physical stream variables. The relationships were normalized to produce HSC.

PRINCIPAL FINDINGS AND SIGNIFICANCE

It was found that the log-law adequately predicted velocity distributions for all stream units and transverse locations. Shear stress observations were not significantly different than predicted values, but results were marginal with a high level of variance. All turbulence observations were significantly different than empirical predictions. Sample variance was too high for TI and TKE observations to produce regression equations. Regression equations were proposed for integral time and length scales. ANOVA results showed significant differences in velocity and turbulence measurements between stream units for nearly all variables. However, significant differences by vertical locations were only observed for streamwise velocity distributions. These results contradict existing concepts of open channel turbulence, which have been developed through laboratory experiments. A TKE budget approach was suggested to improve turbulence predictions.

ADCP measurements for velocity magnitude and shear stress (when determined from velocity magnitude using the log law) were adequate. However, three dimensional velocity components and turbulence measurements were inadequate. Sample error was high because high velocities required the instrument to be operated in a "noisy" mode. The instrument sampling volume was too large and sampling frequency too slow to conduct turbulence measurements. These results have broad implications, considering the large numbers of ADCP instruments in use by the USGS and other agencies.

Periphyton shear stress resistance increased with successional development. However, resistance was not a function of time of the year. AFDM scour was a linear function of shear stress. AFDM increased significantly with both successional development and time of the growth season. These results can be used to improve reservoir release management and stream restoration efforts.

HSC curves were produced for both periphyton and macroinvertebrates. This included HSC functions for substrate size and water depth and velocity. Velocity HSC functions reveled an increase in periphyton AFDM and a decrease in macroinvertebrate frequencies with an increase in water velocity. Depth HSC functions revealed a similar but less distinct trend. Particle size HSC functions were less apparent and were found to be dependent on discretization interval. The HSC curves can be combined with a habitat simulation to determine the impacts of a changed flow regime. This will allow for a more thorough investigation of the value of instream flows.